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COMPOSITION OF MATERIALS FROM VARIOUS ELEVATIONS IN AN IRON BLAST FURNACE

BY

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COMPOSITION OF MATERIALS FROM VARIOUS ELEVATIONS IN AN IRON BLAST FURNACE

By S. P. Kinney

INTRODUCTION

The Bureau of Mines recently completed an investigation of the gas composition, temperature, and pressure at a series of planes in a blast furnace making foundry iron in the southern district. Samples of coke, metal, slag, limestone, and stock were recovered from points between the tuyère plane and stock line. If complete and representative samples of stock could be obtained from various points across a series of planes between the stock line and tuyère level while the furnace is in operation, analyses of these samples would present a clear picture of most of the steps in the reduction process. Aside from giving the position of the zones of reduction, calcination, and slag formation, the samples would be valuable in determining where the iron acquires its carbon, sulphur, phosphorus, manganese, and silicon. Such an investigation was suggested by a number of operators who are interested in control of the composition of pig iron.

ACKNOWLEDGMENTS

Acknowledgment is made to the officials and men of the Central Iron & Coal Co., at Holt, Ala., who permitted and helped in this and other investigations. Samples reported herein were analyzed at various stations of the Bureau of Mines, including Minneapolis, Pittsburgh, and Tuscaloosa. Microscopic examination of samples reported was made by R. E. Head, microscopist, Intermountain experiment station, Salt Lake City. Numerous samples were analyzed by H. S. Landers, chief chemist of the Central Iron & Coal Co. Acknowledgment is made to these men and stations for assistance in this phase of the investigation; to D. A. Lyon, chief metallurgist of the Bureau of Mines, under whose direction the investigation was conducted; and to A. C. Fieldner, chief chemist of the bureau and superintendent of the Pittsburgh experiment station.

VISUAL EXAMINATION OF MATERIALS FROM FURNACE

The samples reported were taken from a furnace running on southern red and brown ores and nodules made from pyrite sinter to produce foundry iron. Figure 1 is a section of the furnace, showing the position of sample holes 4, 5, and 6.

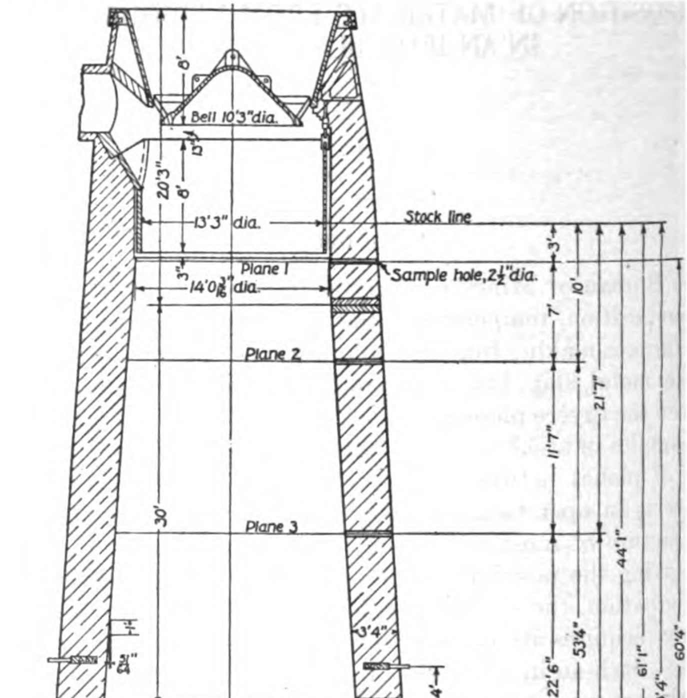

Figure 1.—Section of blast furnace, showing holes through lining for sampling gas and materials from the interior

Hole 4 is near the zone of slag formation and just below the sponge-iron zone. Slag is generally found here, depending on the working condition of the furnace. At this point none of the ore could be identified; reduction was nearing completion before the ore had reached this level, as gas analyses showed. Metal was found intermingled with the various materials in the samples as sponge and small pellets. As would be expected, coke was the only substance that had not changed its identity materially by the time it had reached this plane. Samples of coke were decidedly rounded on the edges, showed signs of abrasion, and contained slightly more metallic iron than the stock coke. Some pieces were covered with semifused slag-forming material. Several samples of thoroughly calcined limestone were obtained. Very few large pieces of limestone were found, these not over 10 mm. in diameter, indicating that after calcination the limestone is thoroughly broken into finely divided pieces and mixed with the charge. Much of the material could not be identified as ore, coke, or limestone, and analysis showed these samples to be a mixture of the three. All the samples but coke taken from plane 5 were fused.

Slag samples contained metal in small pellets, which had impregnated the slag. As will be shown later, the slag was not like that taken from the slag notch or that found at the tuyère level. It was fluffy, had an apparent density of less than 1, and was gray to white in color.

SAMPLING METHODS

Samples of stock were collected from the interior of the furnace by opening the sample hole and allowing the stock to be blown out of the furnace into a metal container; these samples were allowed to cool in an air-tight metal container in a reducing atmosphere.

Samples from hole 5, which is 27 inches above the center line of the tuyères, were collected by allowing the fused material to blow or run out of the furnace into the container.

A number of samples were collected from the center of the furnace at the tuyère level by drilling gas-sampling tubes which had been plugged while in the furnace. The position of the end of the sampling tube when plugged was noted.

PREPARATION OF SAMPLES FOR THE LABORATORY

The samples were composed of a mixture of various materials and were large enough to be separated into various portions for analysis. In general, the procedure was as follows: The sample was weighed and a portion set aside for leaching and determination of cyanide and total alkali. The remainder was divided into coke, metal, slag, limestone, ore, and unidentifiable substances. Much care was needed in obtaining clean samples of metal for analysis. The results reported for analysis of metal are for small clean particles.

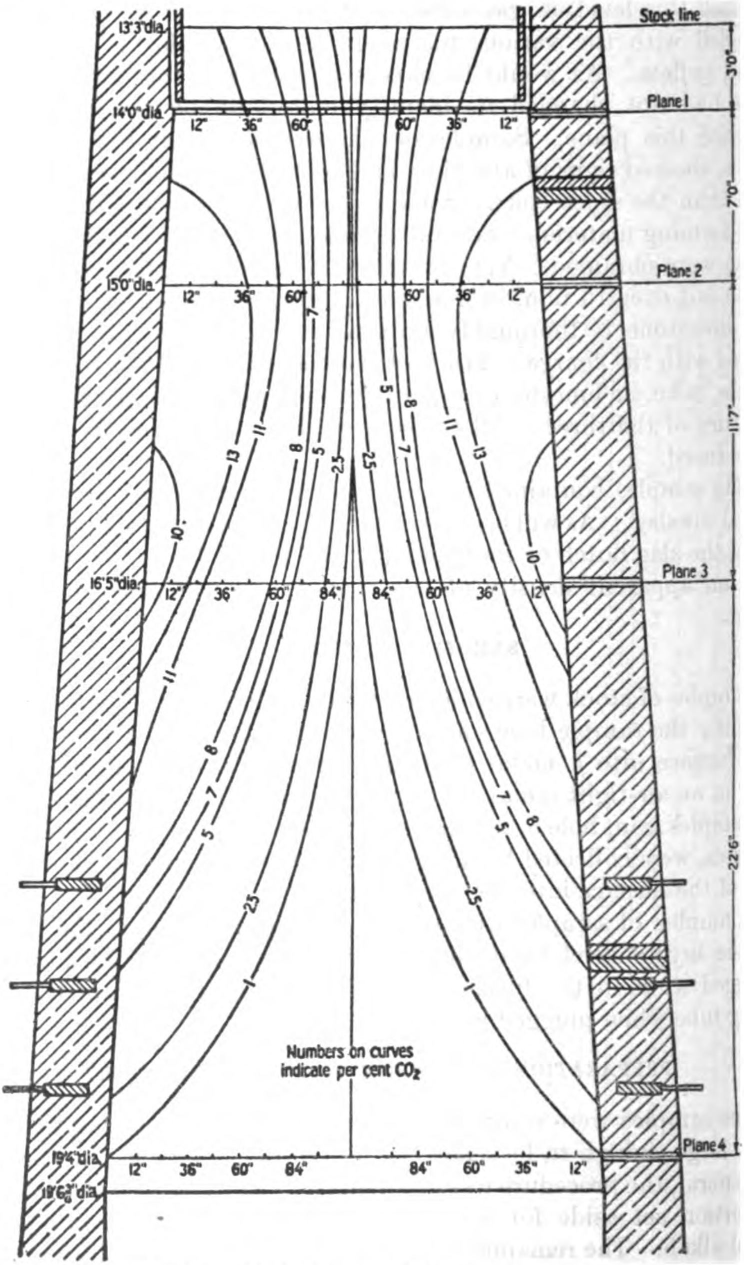

FIGURE 2.—Section of 300-ton furnace, showing lines of equal CO_2 content

TEMPERATURE, PRESSURE, AND GAS COMPOSITION AT VARIOUS PLANES

About 1,000 gas samples were taken to determine the gas composition at the various planes; detailed results of this sampling are reported elsewhere.[1] Figure 2 has been plotted from the gas analyses to show the lines of equal CO_2 content. Table 1 shows the temperature, pressure, and average gas composition at each plane; the last was determined by integration of the results of gas sampling across each plane. Figure 3 gives the average CO and CO_2 percentages.

Table 2 gives analyses of representative samples of stock, weighing 26 to 200 pounds, collected from plane 4. The iron content was checked against the calculated iron content of the stock at this point and the analysis of the ore burden.

Tables 3 and 4 give analyses of samples of metal cast compared with samples of metal obtained from the tuyère plane and from sample holes 4, 5, and 6. In Table 5 samples of slag from the cinder notch are compared with samples obtained from the various sample holes. Analyses of a number of samples of coal and coke are given in Table 6; these contain analyses of samples of bone and slack (used for making foundry coke), a composite sample of furnace coke, and samples of coke taken from hole 4 and the iron notch.

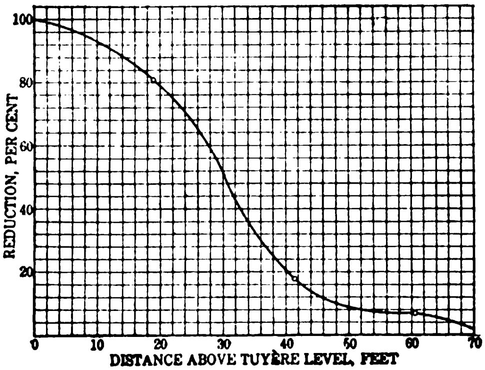

FIGURE 3.—Relation between distance above tuyère level and percentage of reduction

TABLE 1.—*Position of planes, temperatures, and pressures and analysis of gases by weight and volume, compared with bosh gas and air* [a]

Planes	Above tuyère [b]	Below stock line	Pressure, pounds per square inch	Temperature, °C.	Gas analysis							
					Per cent by volume				Per cent by weight			
					CO_2	CO	H_2	N_2	CO_2	CO	H_2	N_2
1	2	3	4	5	6	7	8	9	10	11	12	13
	Ft. in.	*Ft. in.*										
Top gas				168.0	9.9	28.1	2.0	60.0	14.9	27.0	0.1	58.0
No. 1	60 4	3 0	0.45	204.4	10.30	27.04	1.87	60.79	15.5	25.9	.1	58.5
No. 2	53 4	10 0	2.3	[c] 465.5	12.14	26.50	1.69	59.67	18.1	25.1	.1	56.7
No. 3	41 9	21 7	3.7	[c] 745.0	9.02	28.62	1.64	60.72	13.7	27.6	.1	58.6
No. 4	19 3	44 1	10.4	[c] 853	1.10	33.6	.8	64.50	1.73	33.5	.06	64.65
Bosh gas				[d] 1,350	.0	34.10	.79	65.11	.0	34.16	.05	65.79
Air				513.8	.0	.0	20.9	79.08	.0	.0	23.15	76.85

[a] Composition of gases at each plane derived by integration of average analyses of a series of samples taken between inwall and center of furnace.

[b] Distance from center line of tuyères.

[c] Average temperature between inwall and center of furnace.

[d] Assuming average temperature of plane 5 as 1,350° C.

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[1] Kinney, S. P., Royster, P. H., and Joseph, T. L., Reactions in an Iron Blast Furnace: Tech. Paper 391, Bureau of Mines. (In press.) Reactions in the Iron Blast Furnace: Repts. of Investigations, Serial 2747, Bureau of Mines, 1926, 11 pp.

TABLE 2.—*Analyses of samples of stock removed from plane 4, showing per cent of Fe, FeO, and Fe_2O_3*

No.	Iron			SiO_2	Al_2O_3	CaO, MgO	Iron [1]		
	Metallic	Ferrous	Ferric				Metallic	Ferrous	Ferric
1	51.66	2.04	3.91	14.26	9.0	2.54	89.7	3.5	6.8
2	30.02	2.03	3.97	[2] 14.22	....	7.58	83.3	5.6	11.1
3	32.50	1.60	3.28	13.10	8.2	4.30	86.8	4.4	8.8
							86.6	4.5	8.9

[1] Iron, 100 per cent.

[2] Includes Al_2O_3.

TABLE 3.—*Composition of metal produced compared with samples from tuyère plane*

Date	Source	Time	Analysis, per cent				Total carbon	Analysis by—
			Si	S	P	Mn		
Oct. 14, 1923	Cast	10.30 a. m.	2.30	0.041	0.81	0.76	....	(1)
Do	Tuyère	11.30 a. m.	2.60	.069	.32	1.92	3.78	(2)
Do	Cast	5.30 p. m.	2.14	.041	.81	.63	....	(1)
Oct. 17, 1924	do	10.30 a. m.	2.40	.061	.55	.60	....	(1)
Do	Tuyère	11.30 a. m.	.65	.17	.20	.68	3.94	(2)
Do	Cast	5.30 p. m.	2.05	.047	.49	.56	....	(1)
Oct. 30, 1924	do	10.30 a. m.	2.04	.042	.47	.54	....	(1)
Do	Tuyère	11.30 a. m.	2.30	.137	.31	.86	3.77	(2)
Do	Cast	5.30 p. m.	2.82	.038	.52	.71	....	(1)
Jan. 18, 1924	Tuyère	11.30 a. m.	....	....	....	....	3.25	(2)
May 4, 1923	do	9.30 a. m.	2.82	.095	....	.34	1.55	(3)
Do	do	1.30 p. m.	.66	.101	.30	.37	2.23	(3)
May 5, 1924	do	9.30 a. m.	3.34	.020	.26	.48	2.78	(3)

[1] J. S. Landers, chief chemist, Central Iron & Coal Co., Holt, Ala.

[2] Bureau of Mines, Minneapolis, Minn.

[3] From east and west furnaces, American Rolling Mill Co., Columbus, Ohio; analysis by company.

TABLE 4.—*Composition of metal produced, compared with samples from holes 4 and 5*

Date	Source	Time	Analysis, per cent				Carbon			Analysis by—	No. of sample
			Si	S	P	Mn	Total	Graphitic	Combined		
Jan. 31, 1924	Cast	5.30 a. m.	2.44	0.049	0.72	0.53	....	....	....	(1)	1
Do	do	10.30 a. m.	2.31	.039	.76	.51	....	....	....	(1)	2
Do	Hole 5	11.30 a. m.	2.29	.185	.52	.71	3.17	2.90	0.27	(2)	[3] 3
Do	do	do	1.70	.030	.45	1.52	3.42	2.90	.52	(2)	4
Do	do	do	2.19	.028	....	.65	....	....	....	(1)	[4] 5
Do	do	do	2.72	.090	.49	1.43	3.44	3.22	.22	(2)	[3] 6
Do	Cast	5.00 p. m.	2.39	.029	.52	.56	3.64	3.06	.58	(2)	7
Do	do	do	2.29	.028	.59	.54	....	....	....	(1)	8
Feb. 11, 1923	do	5.30 a. m.	4.42	.041	.75	.64	....	....	....	(1)	9
Do	do	10.30 a. m.	3.07	.044	.75	.61	....	....	....	(1)	10
Do	do	do	3.51	.055	.68	1.32	3.45	2.75	.70	(2)	11
Do	Hole 5	11.30 a. m.	3.42	.404	.51	1.47	3.19	2.81	.38	(2)	[3] 12
Do	do		3.20	.330	.75	.85	....	....	....	(1)	13
Feb. 20, 1924	Cast	10.30 a. m.	1.39	.060	.63	.52	....	....	....	(1)	14
Do	Hole 4	11.30 a. m.	.24	.080	.14	.24	1.62	....	....	(1)	15
Do	Cast	5.30 p. m.	1.79	.019	.64	.68	....	....	....	(1)	16
Feb. 21, 1924	do	10.30 a. m.	1.53	.023	.63	.46	....	....	....	(1)	17
Do	Hole 4	11.30 a. m.	....	....	....	....	.84	....	....	(1)	18
Do	Cast	5.30 p. m.	1.20	.023	.75	.46	....	....	....	(1)	19
Feb. 25, 1924	do	10.30 a. m.	2.36	.036	.56	.65	3.20	....	....	(1)	20
Do	Hole 4	11.30 a. m.	.24	.075	.39	.24	1.58	.020	1.60	(1)	[5] 21
Do	Cast	5.30 p. m.	2.96	.025	.54	.52	....	....	....	(1)	22
Feb. 26, 1924	do	10.30 a. m.	2.45	.021	.54	.47	3.41	....	....	(1)	23
Do	Hole 4	11.30 a. m.	.080	.057	.45	.18	1.22	....	....	(1)	[6] 24
Do	Cast	5.30 p. m.	2.16	.021	.057	.52	....	....	....	(1)	25

[1] J. S. Landers, chief chemist, Central Iron & Coal Co., Holt, Ala.

[2] Bureau of Mines, Minneapolis, Minn.

[3] Metal pellets removed from slag.

[4] 50-gram sample.

[5] 98.11 per cent metallic iron.

[6] 98 per cent metallic iron.

TABLE 5.—*Composition of furnace slag, compared with samples from holes 4, 5, and 6*

Date	Source	Composition of slag,[1] per cent							Ratio[2]	Analysis by—	Sample No.	Remarks
		SiO_2	Al_2O_3	CaO	MgO	S	FeO	MnO				
Dec. 19, 1924	Cinder notch	36.80	17.20	[3]43.92	------	1.52	------	----	0.79	(4)	1	Composite sample 24 hours. Slag sample entered sample tube.
Dec. 20, 1924	Center of tuyère.	36.55	15.02	31.65	12.81	.77	1.89	0.91	.85	(5)	2	When tube was in center of hearth.
Do	do	38.60	17.88	30.40	11.06	1.72	------	----	.71	(4)	3	Do.
Do	Cinder notch	36.80	17.20	[3]44.04	------	1.46	------	----	.79	(4)	4	Composite sample, 24 hours.
Dec. 21, 1924	do	37.80	17.53	[3]42.70	------	1.47	------	----	.75	(4)	5	Do.
Jan. 30, 1924	do	37.00	18.03	[3]43.02	------	1.44	------	----	.76	(4)	6	Do.
Jan. 31, 1924	Hole 5	36.15	21.90	30.90	9.46	1.28	.50	.24	.68	(5)	7	Slag from sample hole 5.
Do	do	38.60	10.52	[3]47.59	------	2.34	.83	.15	.93	(4)	8	Do.
Do	Cinder notch	35.45	21.84	33.90	6.37	1.24	.49	.36	.68	(5)	9	Composite sample, 24 hours.
Do	do	35.20	17.86	[3]44.70	------	1.74	------	----	.82	(4)	10	Do.
Feb. 10, 1924	do	36.80	10.03	[3]42.07	------	1.60	------	----	.73	(4)	11	Do.
Feb. 11, 1924	Hole 5	35.24	10.02	[3]51.94	------	2.30	------	----	1.08	(4)	12	Slag from sample hole 5.
Do	do	31.95	17.61	33.08	14.01	2.83	.756	.33	.92	(5)	13	200-pound sample, 11.50 a. m., contained metal shot. Slag density, less than 1.
Do	do	32.50	14.07	33.70	16.21	2.08	1.387	.57	1.02	(5)	14	Color, gray to black; soft and porous
Do	Cinder notch	32.9	17.27	31.50	13.03	3.27	3.90	.26	.84	(5)	15	1.30 p. m. flush.
		32.30	16.02	31.40	13.01	2.44	2.32	.57	.88	(5)	16	2.15 p. m. flush.
Do	do	35.20	20.87	[3]41.22	------	2.21	------	----	.71	(4)	17	3 p. m. flush.
Do	do	36.40	17.20	[3]44.24	------	1.56	------	----	.80	(4)	18	Composite sample, 24 hours.
Feb. 20, 1924	Hole 4	34.00	15.86	[3]27.22	------	.32	4.00	----	[6].55	(4)	19	Contained 18 per cent carbon.
Do	Cinder notch	34.10	16.70	[3]47.06	------	1.64	------	----	.90	(4)	20	Composite sample, 24 hours.
Feb. 21, 1924	do	33.24	14.36	[3]50.28	------	1.66	------	----	1.02	(4)	21	Do.
Feb. 25, 1924	Hole 4	43.20	13.86	[3]41.48	------	.96	------	----	.72	(4)	22	
Do	Cinder notch	34.60	16.70	[3]46.56	------	1.64	------	----	.88	(4)	23	Do.
Feb. 26, 1924	Hole 4	44.00	14.50	25.45	8.76	1.01	4.06	----	[6].56	(4)	24	Contained 2 per cent carbon.
Do	Cinder notch	34.44	15.64	[3]47.73	------	1.68	------	----	.92	(4)	25	Composite sample, 24 hours.

---

[1] Fe and Mn calculated to FeO and MnO. Al_2O_3 determined by difference, Fe_2O_3 and Mn_3O_4 subtracted from R_2O_3.

[2] Ratio=(CaO÷MgO)+(SiO_2+Al_2O_3+S).

[3] Includes MgO.

[4] H. S. Landers, chief chemist, Central Iron & Coal Co., Holt, Ala.

[5] Bureau of Mines laboratory, Minneapolis, Minn.

[6] Carbon and iron oxide calculated out.

TABLE 6.—*Analyses of coal and coke samples* [1]

Constituents	Bone [2]	Slack		Furnace coke [5]	Coke from sample hole 4				Coke from iron notch	
		Sample A [3]	Sample B [4]		Feb. 20	Feb. 21	Feb. 25	Feb. 26	Sample 1	Sample 2
PROXIMATE ANALYSIS										
Volatile matter	24.3	32.5	30.3	1.0	--------	2.7	2.7	--------	2.2	0.6
Fixed carbon	39.6	58.7	58.3	81.1	--------	72.0	63.5	--------	50.3	42.8
Ash	36.1	8.8	11.4	17.9	--------	24.9	33.8	--------	47.5	56.6
	100.0									
ULTIMATE ANALYSIS										
Hydrogen	3.6	4.9	4.8	.4	--------	.5	.4	--------	--------	--------
Carbon	53.1	77.8	74.9	80.0	--------	75.5	63.3	--------	--------	--------
Nitrogen	.9	1.6	1.5	.6	--------	.8	.6	--------	--------	--------
Oxygen	5.6	5.8	6.0	.1	--------	.0	.0	--------	--------	--------
Total sulphur [6]	.7	1.1	1.4	1.0	0.78	.80	.65	0.76	.99	.9
Pyritic	.30	.45	--------	.20	.04	.06	.07	.03	.45	.67
Sulphate	.01	.01	--------	.02	.03	.03	.04	.02	.01	.10
Organic	.43	.65	--------	.64	.57	.56	.38	.57	.27	.06
Free	--------	--------	--------	.14	.14	.16	.16	.14	.26	.16
Ash	36.1	8.8	11.4	17.9	26.0	24.9	33.8	27.0	47.5	56.6
Calorific value:										
Calories	5,189	7,700	7,406	6,500	--------	6,194	5,606	--------	--------	--------
B. t. u	9,340	13,060	13,330	11,700	--------	11,150	10,090	--------	--------	--------

[1] Analyses by Bureau of Mines coal laboratory, Pittsburgh, Pa.
[2] Sample of poor grade of bone.
[3] Sample of coal used for foundry coke.
[4] Coal used for making blast-furnace coke, February, 1924, composite monthly sample.
[5] Furnace coke, composite monthly sample for February, 1924.
[6] Forms of sulphur determined by method given in Bureau of Mines Technical Paper 254.

DISCUSSION OF RESULTS

GAS SAMPLING

The results of gas sampling at the various planes are shown in Table 1, and the CO_2 content is plotted in Figure 2. By determining the amount of oxygen entering the furnace in combination with the metallic oxides and the amount of oxygen removed from the oxides of the metals at the various planes, the amount of reduction could be judged. The results show that 6 per cent of the work of reduction was complete at plane 1, 18.9 per cent at plane 3, and 80.5 per cent at plane 4; it was assumed that the process was complete at the tuyère plane. These results have been plotted in Figure 4.

STOCK SAMPLING

Stock sampling at plane 4 is shown in Table 2, which indicates that 86.6 per cent of the iron in the burden is in the metallic form, 4.5 per cent as FeO, and 8.9 per cent as Fe_2O_3. Gas sampling indicates that 80.5 per cent of the iron in the burden is in the metallic form; stock sampling shows 86.6 per cent at plane 4.

If both results are considered, 80 to 85 per cent of the iron in the burden has been reduced from the oxide state to metallic iron and is disseminated throughout the gangue material as sponge or small metallic particles. This fact might be of interest to those who are working on problems of ore beneficiation, especially those interested in the concentration of the hard red oölitic or fossiliferous ores of the southern district.

About 70 per cent of the ore used in the southern district is red hematite. Tests have shown that this ore is not generally amenable to gravity concentration, and that the difficulty of treatment in a blast furnace increases with the silica content. There is, however, a possibility of reducing the oxides in these refractory ores to the metallic state and then separating the iron from the gangue material by concentration.

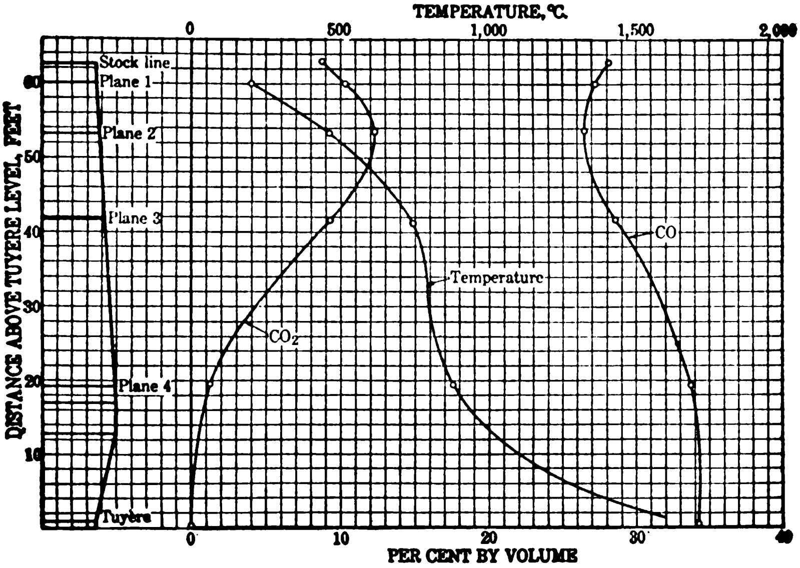

FIGURE 4.—Relation between CO, CO_2, temperature, and distance above tuyères

MICROSCOPIC EXAMINATION OF STOCK

Microscopic examination by R. E. Head, microscopist for the Bureau of Mines at Salt Lake City, of stock samples from plane 4 showed that they consist of three types of particles, grouped by physical characteristics and metallic iron content. These particles may be classified as (1) normal sponge iron, (2) oölitic sponge iron, containing comparatively little gangue matter, and (3) particles composed of metallic iron disseminated in gangue containing as high as 50 per cent foreign matter; (2) and (3) are shown in Figures 5 and 6.

If the particles of high metallic content (normal and oölitic types) could be separated from the disseminated iron particles by selective magnetic methods, a good grade of metallic iron product would be obtained, and tailings consisting largely of the particles containing disseminated iron in gangue could be crushed for further treatment.

As the metallic iron particles in the mixed grains are small, it is thought that crushing to minus 150 mesh will be necessary to free them.

Furnace treatment has rendered the gangue material somewhat brittle, therefore it is thought that direct impact crushing, such as by a stamp or rod mill (dry), might give the best results in freeing the metallic iron from the gangue.

METALLOIDS

In its transformation to metallic iron, iron oxide takes up silicon, sulphur, manganese, phosphorus, and carbon, and furnace operators will be interested to know where and in what quantities these elements enter the metal. Tables 3 and 4 compare the composition of the metal produced with that of the metal samples obtained from sample holes 4, 5, and 6. The results show that the metallic iron at plane 4 has taken up large amounts of these elements.

Metal produced from this furnace generally contains 2 to 3.5 per cent silicon, less than 0.05 per cent sulphur, 0.50 to 0.70 per cent phosphorus, 0.45 to 0.70 per cent manganese, and 3 to 4 per cent carbon. These figures and the analyses of individual casts in Tables 3 and 4 might be used as a basis of comparison, with the metal obtained from the sample holes.

SILICON

That the amount of silicon in the metal depends upon the temperature of the hearth and the composition of the slag[2] is generally conceded. Royster and Joseph[3] have advanced the theory that the content of silicon in the metal depends upon that in the coke ash.

Table 7 has been arranged to show the silicon content of the metal taken from the various sample holes, compared with the silicon content of the metal produced at cast:

TABLE 7.—*Comparison of the average silicon content of several casts of metal with the silicon content of samples from various sample holes*

Hole No.	Silicon in metal, per cent		Per cent of total silicon entering metal
	At sample hole	Cast [a]	
4	[b] 0.42	1.97	
5	2.55	2.92	87.4
6 (tuyère level)	2.95	3.00	98.3

[a] Average of a number of samples from casts before and after each sample was taken at sample holes.
[b] Probably included SiO_2.

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[2] Johnson, J. E., jr., Principles, Operation and Products of the Iron Blast Furnace. New York, 1918, p. 243.

[3] Royster, P. H., and Joseph, T. L., "Pyrometry in blast-furnace work": Trans. Am. Inst. Min. and Met. Eng., volume on "Pyrometry," 1921, pp. 544–558; discussion, pp. 558–567.

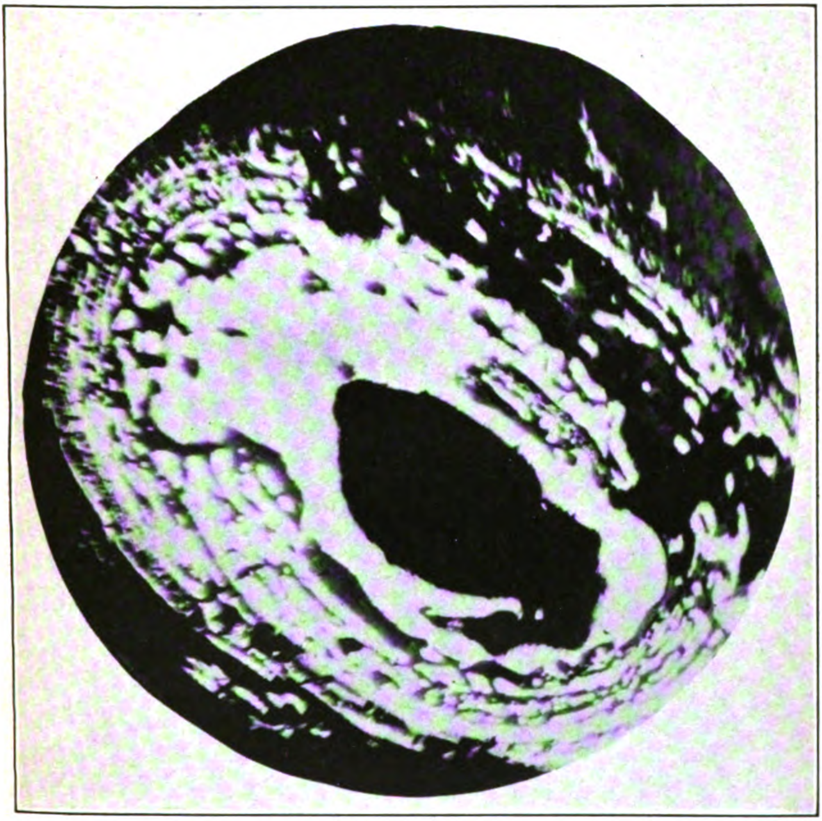

FIGURE 5.—Particle of oölitic iron, showing hollow center and alternate bands of metallic iron and gangue with slag. Magnification × 125; actual field approximately 0.8 mm..

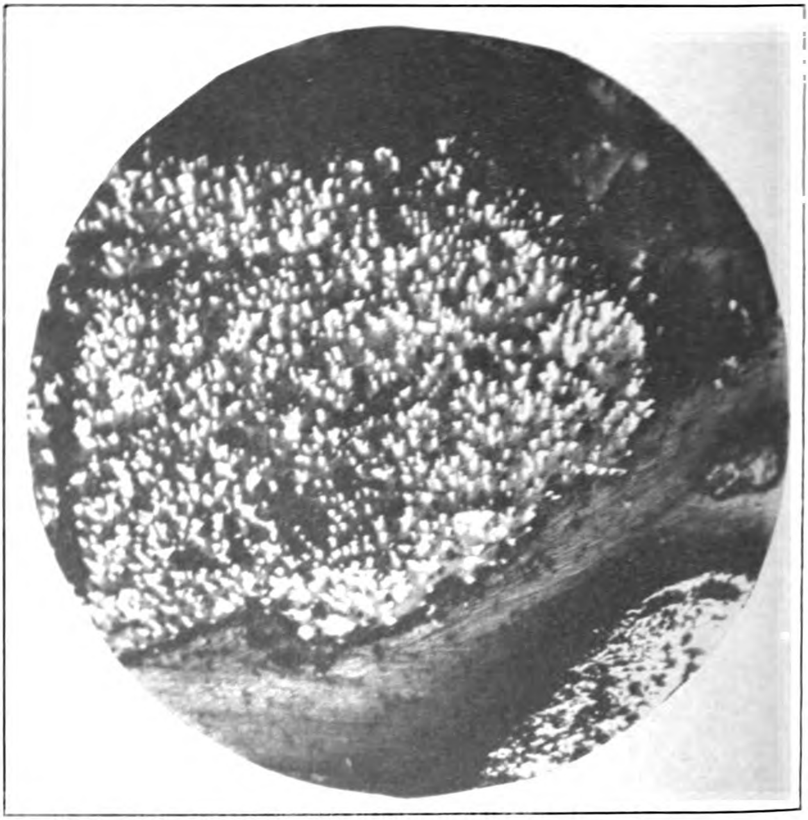

FIGURE 6. Portion of briquetted particle containing disseminated metallic iron in gangue. None of the metallic areas are larger than 0.01 mm. in diameter. (The diameter of openings of a 300-mesh sieve is 0.043 mm.) Magnification × 125; actual field approximately 0.8 mm.

Silicon is reduced by carbon in the electric furnace at 1,460° C. in the presence of iron; ferrosilicon is formed at about 1,200° C. From this, it is logical to believe that, as the temperature of plane 4 was 853° C. and that of plane 5, 1,350° C., the metal would take up a considerable part of its silicon in the cast by the time it had reached plane 5. Table 7 shows that the average silicon content of the metal at cast was 2.92 per cent and at hole 5, 2.55 per cent. The metal had taken up 87.4 per cent of its silicon by the time it reached this point in the furnace. At the tuyère plane the metal had acquired an additional 11 per cent silicon.

The data show that most of the silicon enters the metal in the bosh of the furnace. As the temperature required to reduce silicon is higher than that required to reduce other oxides it would be expected that the silicon would enter the metal in the lower part at the bosh of the furnace rather than higher up. It is probably correctly assumed that the silicon content of the metal depends upon the temperature maintained in the furnace. High temperature is the first prerequisite for obtaining high silicon.

The silica in the coke ash has little effect on the resultant amount of silicon entering the metal. The coke does not release its silica until combustion occurs in the relatively small zone of combustion at the nose of each tuyère. Before the metal reaches this level it has taken up the greater part of the silicon it will acquire, but the temperature of the combustion zone probably assists the last traces of silicon to enter the metal. There is no reason, however, to believe that the small amount of silicon taken up at the tuyère level is selected from the silicon in the coke ash in preference to that from other sources.

MANGANESE

Manganese oxide is reduced in the presence of carbon at 1,105° C.; ferromanganese forms at 1,030° C. Manganese will enter the metal in the zone of fusion, but actual samples show that a small amount of manganese has entered the metal at plane 4. The analyses in Table 3 show that the average manganese content of the metal from 15 casts was 0.53 per cent and that the metal samples taken from planes 4 and 5 contained 0.22 per cent and 1.10 per cent, respectively. Approximately one-third of the manganese had entered the metal while it was in the sponge-iron zone. While the metal was in the bosh of the furnace, traveling from plane 4 to plane 5, it took up 1.10 per cent, about twice the quantity found in the metal samples obtained from cast. It must be pointed out that those samples were taken at hole 5 just above the tuyère level. On comparing these results with those of metal samples taken at cast it would appear that considerable manganese had been oxidized while the metal was passing through the tuyère zone. This finding is rather unexpected inasmuch as Bessemer, open-hearth, and electric-furnace reactions prove that silicon is oxidized preferentially or along with the manganese. Here manganese is reduced by half while silicon is gaining 12 per cent. The fact that the metal loses considerable sulphur at the same time indcates that the manganese may be lost as manganese sulphide.

PHOSPHORUS

Phosphorus charged with the raw material generally enters the metal and it would be desirable to eliminate it, but so far this is not practicable. It is generally conceded that all of the phosphorus entering the furnace finds its way to the metal, unless the furnace is working abnormally. Careful examination was made of the analyses of the materials charged in the furance, and it was found that the results agreed with these statements. Samples from 15 casts of metal gave an average phosphorus content of 0.64 per cent, samples taken from hole 4, 0.32 per cent, and from hole 5, 0.54 per cent. The results show that half of the phosphorus had entered the metal or was very intimately in contact with the metal before it had reached plane 4, and approximately 84 per cent had entered the metal by the time it had reached plane 5. The ease with which the metal takes up the phosphorus is readily shown by the results. As phosphorus is not completely reduced until a temperature of 1,150° C. is attained, it is quite possible that it was not in phosphide form until a point well down in the bosh was reached.

CARBON

For a long time it has been known that iron will take up various elements when heated in their presence, and carbon is probably absorbed most readily. These experiments show that the order in which iron absorbs such elements during the blast-furnace process is as follows: Carbon, sulphur, phosphorus, manganese, and silicon.

The analyses of metal samples in Table 4 indicate that the iron has readily absorbed a large amount of carbon by the time it reaches plane 4 and that the carbon in the metal from the casts contained an average of 3.39 per cent. At plane 4 the metal contained 1.29 per cent, and at plane 5, 3.19 per cent, while four samples from the tuyère plane gave 3.68 per cent. More than one-third of the carbon has been taken up by the metal by the time it reaches plane 4; the remainder is absorbed in the bosh of the furnace before reaching the tuyère level.

SULPHUR

Table 8 gives the average sulphur content of a number of samples of metal taken at sample holes 4 and 5 and at the tuyère level. The results are compared with the sulphur content of metal samples taken from casts just before and after the samples were obtained from the various sample holes.

TABLE 8.—*Comparison of sulphur content of metal samples taken at various elevations in the furnace with the sulphur content of metal produced* (*per cent*)

Source	At sample hole	Cast
Hole 4	0.070	0.028
Hole 5	.179	.041
Tuyère level	.072	.045

The sulphur taken up in the metal above plane 4 was absorbed from the coke while the iron was spongy and may have been absorbed by the oxides of iron before reduction. Wuerst and Wolff[4] have shown that iron oxides will take up sulphur, and Hilgenstock[5] reports the results of some experiments on the absorption of sulphur by iron when heated in the presence of coke. Table 9 gives the results of these experiments:

TABLE 9.—*Experiments on the absorption of sulphur by iron* (*after Hilgenstock*)

Condition of metal	Si	Mn	C	S
Original metal	0.38	0.45	0.62	0.04
Metal after fusion with coke	.58	.18	1.80	.50

The experiments of Hilgenstock show that the metal will absorb sulphur when heated in the presence of coke. These experiments were performed on a laboratory scale. The results of Table 3 show that a similar result is found in the blast furnace. Analyses of the metal samples taken at plane 4 show that the metal has taken up 0.070 per cent of sulphur, more than the tolerant amount. It has been increased to twice the tolerant limit by the time the metal has reached the elevation of plane 5, 27 inches above the tuyère level. Desulphurization has taken place between this level and the tuyère level, where the sulphur content had been reduced to 0.072 per cent. The ease with which the metal takes up sulphur (above plane 4) in the sponge-iron zone is readily shown in the analyses. The metal evidently continues to take up sulphur until it is well down into the bosh of the furnace, and desulphurization therefore takes place between a point below plane 5 and the crucible. This will be discussed later.

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[4] Wuerst, F., and Wolff, P., "Sulphur in coke and its behavior in the blast furnace": Jour. Iron and Steel Inst., vol. 67, 1905, pp. 406–432.

[5] Hilgenstock, G., ["Elimination of sulphur from iron"]: Stahl u. Eisen, Jahrg. 13, 1893, pp. 451–462; Jour. Iron and Steel Inst., vol. 44, 1893, pp. 435–437.

AVAILABLE SULPHUR COMPARED WITH THAT TAKEN UP BY METAL

Actually the quantity of sulphur taken up by the metal is small compared with that which is available in the furnace. A study of the composition of the materials entering the furnace shows that about 0.0150 pound of sulphur is charged for every pound of iron produced. The tolerant limit on sulphur in the metal produced is 0.050 per cent, or 0.0005 pound of sulphur per pound of metal. It may be seen from this that the metal produced at cast, if under the tolerant limit for sulphur, will contain less than 3.33 per cent of the sulphur charged. Comparing this with the results on plane 4 it will be seen that the metal has taken up 4.7 per cent of the available sulphur and at plane 5, 12 per cent.

DISCUSSION OF SULPHUR REACTIONS

The presence of sulphur is detrimental to the blast-furnace process, and in an attempt to improve it much work has been done on the methods of removing sulphur from coke.[6] With this has come a study of the forms of sulphur in coke[7] and a physical-chemical study of the forms of sulphur in coke and their effect on blast-furnace reactions[8] as well as a study of the effect of the presence of sulphur on the cost of producing iron.[9]

The work of previous investigators shows that the blast-furnace gases might be expected to remove some of the sulphur from the coke by the time the latter had traveled from the stock line to the elevation of plane 4. Investigation of a southern furnace by the writer shows that the gases in the interior of the furnace at plane 4 have the following composition: CO_2, 1.1 per cent; O_2, 0.0 per cent; CO, 33.6 per cent; H_2, 0.8 per cent; and N_2, 64.5 per cent.

As the gases approach the stock line the composition changes; the CO_2 increases and the CO decreases. The composition of the gases in the center of the furnace changes little in a column between plane 4 and the stock line; here most of the charge is composed of coke and the gas composition is about as shown above. It would be expected that these gases would affect the sulphur in the coke.

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[6] Powell, A. R., and Thompson, J. H., A Study of the Desulphurization of Coke by Steam: Coal-Mining Investigations, Carnegie Inst. of Technol. and Bureau of Mines, Bull. 7, 1923, 56 pp.

[7] Powell, A. R., "Forms of sulphur in coke": Jour. Am. Chem. Soc., vol. 45, 1923, pp. 1-15

[8] Powell, A. R., "Forms of sulphur in coke and their effect on blast-furnace reactions": Trans. Am. Inst. Min. and Met. Eng., vol. 69, 1923, pp. 567-598; discussion, 599-603.

[9] Joseph, T. L., Effect of Sulphur on the Blast-Furnace Process: Bureau of Mines report (unpublished), 1924.

Table 10 gives examples of a few laboratory experiments by Simmersbach and Wolff,[10] who removed sulphur from coke with blast-furnace gas and its various constituents.

TABLE 10.—*Effects of blast-furnace gas, carbon dioxide, carbon monoxide, and nitrogen on the sulphur in coke*

Temperature, °C.	Per cent of sulphur removed by—			
	Blast-furnace gas	Carbon dioxide (CO_2)	Carbon monoxide (CO)	Nitrogen (N_2)
500	12.84	6.47	12.30	2.41
600	13.27	8.32	16.89	4.90
800	36.83	16.00	30.80	5.90
900	51.52	24.46	37.61	6.97
1,000	54.34	59.24	38.32	17.33

The above figures indicate that much sulphur might be removed from the coke with the gases in the interior of the furnace.

FORMS OF SULPHUR IN COKE

Forms of sulphur in coke which is charged into the furnace are compared with those found in the coke taken from the various sample holes.

These results are given in Table 3 and have been summarized in Table 11, where the ferrous sulphide and free sulphur have been tabulated together. It may be easily seen that the sulphur in the coke has been affected by its travel from the stock line to plane 4.

TABLE 11.—*Sulphur in samples of coke taken from original coke charged, sample hole 4, and the iron notch (per cent)*

Form of sulphur	Original coke	Samples from hole 4			Samples from iron notch		
Ferrous sulphur and free sulphur	0.34	0.18	0.22	0.23	0.17	0.71	0.83
Sulphate	.02	.03	.03	.04	.02	.01	.10
Organic	.64	.57	.56	.38	.57	.27	.06
Loss		.22	.19	.35	.35	.01	.01
	1.00	1.00	1.00	1.00	1.00	1.00	1.00

The free and pyritic sulphur content of the coke has been reduced, while the sulphate sulphur has not been affected to any appreciable extent. The organic sulphur has been slightly reduced three times out of four. The total loss in sulphur is about 25 per cent. It is difficult to follow the coke to the lower part of the furnace on account of its impregnaton with slag, which alters the sulphur determinations, but a number of analyses are given for samples which were taken at the iron notch. Reference to Table 6 will show that the ash has increased in this coke and that the sulphur content is about the same as that in the original coke. The sulphide and free sulphur have been increased, while the organic sulphur has decreased.

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[10] Simmersbach, C., and Wolff, Paul, "Gasverhalten des Kokschwefels in Hochofen": Gluckauf, Jahrg. 41, 1905, p. 906.

The 25 per cent of total sulphur in the coke which has been removed while the coke was traveling from the stock line to plane 4 is made up of free sulphur and ferrous sulphide sulphur. This sulphur has been taken up by the metal, the iron oxides, or the lime, or has been removed from the furnace by volatilization. Results of some laboratory experiments by Powell and analyses of samples of lime and other materials will show how this sulphur has been removed. Powell[11] has shown that when coke, iron, and lime, magnesia, or sodium carbonate are heated most of the sulphur is taken up by the alkali and little enters the metal. Some results obtained by Powell follow in Table 12.

TABLE 12.—*Absorption of sulphur by coke and alkalies (per cent)*

	Original coke	Coke		
		CaO	MgO	Na_2CO_3
Sulphur content:				
Of original coke	0.064	0.064	0.064	0.0[illegible]
Of coke after exposure	.462	.076	.098	.0[illegible]

Powell's data indicate that the sulphur would have entered the metal had it not been for the presence of the lime, magnesia, or sodium carbonate. In a way the results may be compared with those obtained from the furnace at plane 4, where it has been shown there was 0.070 per cent sulphur in the metal.

RESULTS OF ANALYSES OF SAMPLES OF LIMESTONE OBTAINED AT PLANE 4

Limestone was found to be thoroughly calcined and disintegrated when it reached plane 4. It was also noticed that the oxides of iron had been reduced and that the metal pellets, the siliceous material from the ore, and the limestones were thoroughly mixed with the coke. The coke of course was present in larger pieces. It might be said that the lime and the remainder of the charge were in intimate contact, that experiments by Powell and Simmersbach indicated that the limestone would have taken up considerable sulphur, and that this sulphur would come from the free and ferrous sulphide sulphur of the coke. It would be expected that the blast-furnace gases would help to remove sulphur from the coke, and that there might be a preferential absorption of this sulphur by the lime, after the equation of Howe.[12]

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[11] See footnote 3.

$$FeS + CaO + C = Fe + CaS + CO$$

Analyses of representative samples of limestone as charged and as found at plane 4 and a calculation of the probable composition of the limestone at plane 4 compared with the average analysis of a number of samples obtained at plane 4 follow in Table 13:

TABLE 13.—*Analyses of limestone charged, compared with those of samples obtained at plane 4 (per cent)*

Constituent	As charged	Calculated composition at hole 4	Average of actual samples collected at hole 4	Constituent	As charged	Calculated composition at hole 4	Average of actual samples collected at hole 4
SiO	1.00	1.85	0.86	P	0.01	0.02	
Al_2O_3	.60	1.12	3.02	CaO	30.40	56.50	55.2
Fe_2O_3	1.00			MgO	21.40	39.00	40.2
Fe		1.29		CO_2	46.10		
MnO	.03	.56		S	.04	.07	[1] .71

[1] Other samples of limestone analyzed for sulphur, not in this average, gave 0.83, 0.24, and 0.90 per cent S.

These figures show that the limestone has taken up considerable sulphur.

COMPARISON OF SULPHUR AVAILABLE AND AMOUNT TAKEN UP BY LIMESTONE AT PLANE 4

It has been shown that approximately 0.015 pound of sulphur is charged per pound of iron produced, and that 4.76 per cent of this has been taken up by the metal by the time it has reached plane 4. Table 8 shows that 25 per cent of the sulphur has been removed from the coke; if this is compared with the amount of limestone at plane 4 and its sulphur content a check should be obtained. Furnace reports show that at plane 4, 0.563 pound of lime is available per pound of metal produced. Results of analysis of the limestone showed 0.71 per cent sulphur, which is equivalent to 0.0039 pound of sulphur per pound of iron, or 0.0039/0.0150 (26 per cent). In other words, the limestone at plane 4 has taken up about 26 per cent of the sulphur in the charge.

The analyses of limestone and metal samples taken at plane 4 show that 26 per cent of the available sulphur has combined with the lime and 4.76 per cent of the available sulphur has been taken up by the metal. Analyses of coke samples at plane 4 indicate that 25 per cent of the sulphur in the coke, in the form of free and ferrous sulphide, has been removed. Summing up, apparently about 30 per cent of the available sulphur has been taken up by the limestone and the metal. It is undoubtedly true that the removal of ferrous sulphide sulphur from the coke continues until the coke is well down in the bosh of the furnace, that this removal is aided by the ascending gases, and that the sulphur in the gases is taken up by the stone and metal. This would account for the additional 4 per cent of sulphur shown in the above balance.

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[12] Howe, H. M., Iron, Steel, and Other Alloys. 2d ed., New York, 1906, p. 402.

FUNCTION OF VARIOUS PARTS OF FURNACE AND RELATION TO SULPHUR REACTIONS

Above plane 4 the function of the furnace is one of drying, calcination, and reduction, and the formation of sponge iron. In this zone the free sulphur in the coke is first reduced to ferrous sulphide, while the sulphur in the form of sulphate and the sulphur in solid solution are not attacked. Powell has shown that at any given temperature the partial pressure of the organic sulphur is much lower than that for sulphur in the form of ferrous sulphide, also that organic sulphur will not readily change into any other form. As the coke reaches the sponge-iron zone the temperatures and the decomposition pressure of the ferrous sulphide sulphur increase. The ferrous sulphide sulphur tends to pass from the coke to the lime and the metal. As the lime is in intimate contact with the coke and the rest of the charge the reaction may be preferential absorption of sulphur.

Slag formation occurs just above the bosh of the furnace, where the acids and bases in the charge, with the exception of those in the coke ash, have been released and are fairly well mixed; with increasing temperature they become pasty and then fluid. Stock samples from plane 4 show a varying amount of slaglike fused material, depending upon the temperature of the furnace. Probably the slag at plane 4 never exceeds 3 to 4 per cent of the charge. The slag is not of the character of that found at the cinder notch, but is of variable composition. The slag is usually impregnated with particles of metal, iron oxide, and carbon. Table 14 gives analyses of the samples of slag after the metallic iron has been removed.

TABLE 14.—*Analyses of slag samples from plane 4 (per cent)*

Constituent	1	2	3
SiO_2	34.00	43.20	44.00
Al_2O_3	13.86	13.86	14.50
S	.32	.96	1.01
CaO	27.22	41.48	25.45
MgO			8.76
C	18.00		2.00
FeO	4.60		4.06
Total	100.00	99.50	99.78

Most of the material at the elevation of plane 4 is made up of acids and bases which have not reached a state of fusion. Table 15 gives analyses of a number of samples. Particles of metal are found intermingled in the samples. It is noticeable that these particles have not been covered by slag, and many of them probably find their way to a point well down in the bosh of the furnace before they are mixed with slag. Some of the metal may not be covered with slag until it finds its way to the slag bath in the hearth of the furnace. The metal would then continue to take up sulphur from the ferrous sulphide sulphur in the coke until the metal became covered with slag; it would also take up organic sulphur released from the tuyère level by the combustion of coke. This no doubt accounts for the high percentages of sulphur found in the metal samples obtained at plane 5. When the metal becomes covered with slag, desulphurization probably starts. The activity of the slag as a desulphurizing agent depends upon its composition and viscosity. Some of these factors have been discussed thoroughly by Royster and Joseph, and Feild and Royster.[13]

TABLE 15.—*Analysis of nonmagnetic portion from sample hole 4 (per cent)*

Constituents	1	2	3	4	Constituents	1	2	3	4
Fe	17.7	8.0	9.6	5.6	CaO	8.2		14.7	13.2
SiO_2	20.8	10.2	34.6	26.8	MgO			8.9	5.0
Al_2O_3	10.9		11.4	11.1	C	42.4	40.0	14.0	37.2

COMPOSITION OF SLAG

The composition of the slag recovered from the cinder notch is not similar to that found at the elevation of planes 4, 5, or at the tuyère level. Physical measurements, such as viscosity, density, and melting point, of samples taken at the flush are not representative of the slags found in the bosh of the furnace. Feild and Royster have shown that slag composition varies from cast to cast and from one part of a cast to another. In a way this is representative of the variation of slag composition on the interior of the bosh of the furnace, only the differences are more marked. The viscosity, melting point, and density of the samples taken from the slag at the cinder notch are probably fairly representative of the slag which rests on the metal, but are not at all representative of that which is being formed in the bosh of the furnace or that which is formed at the tuyère level. The writer has often seen flushes of average composition followed by flushes that were black and contained slag of an entirely different composition.

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[13] Royster, P. H., and Joseph, T. L., "Pyrometry in blast-furnace work": Trans. Am. Inst. Min. and Met. Eng., volume on "Pyrometry," 1921, pp. 544-558; discussion, pp. 558-567.

Feild, A. L., and Royster, P. H., "Temperature-viscosity relations in the ternary system, $CaO-Al_2O_3-SiO_2$": Trans. Am. Inst. Min. Eng., vol. 58, 1918, pp. 60-64; Tech. Paper 189, Bureau of Mines, 1918, 35 pp. Slag-Viscosity Tables: Tech. Paper 187, Bureau of Mines, 1918, 37 pp.

Although the slag at the cinder notch may be normal the slag that may run back in a tuyère blowpipe may be black and of a different character. In other words, the slag as tapped is not completely formed until it reaches the metal bath; the bosh and hearth of the furnace are not efficient mixing chambers. There may be a lean slag at one side of the furnace with a rich one at the other. These effects are probably caused by the nonuniformity of materials and uneven movement of stock, caused by the localized combustion zones at the tuyères, all of which affect the elements entering the metal. Such evidence strongly indicates that the slag in the hearth and bosh of the furnace is not uniform in composition and that it would be desirable to study the physical properties of slags which are representative of those found in the bosh and near the tuyères of the furnace, rather than the properties of those that have passed through the furnace and have found their way to the slag dump.

In the upper part of the bosh where the slag first appears there is an excess of lime which tends to form a limy slag. The slag does not take up its total silica until it has reached the level of the tuyères, where the silica in the coke ash is released. Until the slag reaches this point it is likely to be very limy; in fact, the higher the ash in the coke the more limy the slag. This is probably an advantage to sulphurization but does not cause smooth working of the furnace. It has been shown that 25 per cent of the sulphur of the coke has been transferred from the coke to the metal and slag by the time the charge has reached the top of the bosh, and 75 per cent of the sulphur in the coke is released in the bosh and tuyère zone of the furnace. The organic sulphur in the coke is released at the tuyères by means of combustion of the coke and is then taken up by the limy slag in the bosh of the furnace.

REMARKS ON SULPHUR CONTROL

A number of investigators have shown that liming of coke and the treatment of coke by steam, carbon monoxide, nitrogen, and other gases will remove part of the sulphur from the coke[14] as ferrous sulphide. Continuation of the above processes is being carried on in the upper part of the furnace. The results of sampling coke at plane 4 show that the lime and the blast-furnace gases have removed about 25 per cent of the sulphur from the coke, and that this represents about half of the sulphur which was present in the coke as ferrous sulphide and free sulphur. The remaining 75 per cent of the original sulphur in the coke must be removed in the bosh of the furnace; 20 per cent is present as ferrous sulphide and is probably removed before

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[14] For review of previous work see "A Study of the Desulphurization of Coke by Steam," by A. R. Powell and J. H. Thompson, Coal-Mining Investigations, Carnegie Inst. of Technol. and Bureau of Mines, Bull 7, 1923, pp. 3-12.

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the coke reaches the tuyères, while the remainder is present as sulphate and organic sulphur, which is released from the coke at the time of combustion. The greater part of the sulphur is removed when the coke is near the tuyères; this sulphur is thrown into the gas and then into the metal or slag. These conditions cause most of the removal of sulphur from coke and the desulphurization of the metal to take place in a comparatively small zone in the lower part of the furnace.

SUMMARY AND CONCLUSIONS

1. Results of sampling stock and gas in the upper part of the blast-furnace stack show that 80 to 85 per cent of the iron in the burden has been reduced to the metallic form by the time it has reached a point 19¼ feet above the tuyère level.

2. It has been shown that metal, in the form of sponge iron, has taken up, or is in intimate contact with, considerable quantities of carbon, sulphur, phosphorus, manganese, and silicon by the time it has reached plane 4, which is 19¼ feet above the tuyère level and 8 feet above the bosh level.

3. About 87 per cent of the silicon entering the metal is taken up while the metal is in the bosh above plane 5, and the remaining 12 per cent is taken up between plane 5 and the crucible, 27 inches above the center line of the tuyères and the crucible.

4. It has been shown that the silica in the coke ash has little effect on the amount of silicon in the metal, because the metal has obtained most of its silicon before it reaches the tuyère level.

5. Approximately one-third of the manganese enters the metal or is very intimately associated with it above plane 4. The manganese content of 15 casts was 0.53 per cent; metal samples from planes 4 and 5 contained 0.22 and 1.10 per cent, respectively. Between planes 4 and 5 the metal takes up considerable manganese, part of which is probably oxidized later in the tuyère zone.

6. All of the phosphorus has entered the metal by the time the metal has reached plane 5. Approximately one-half of the phosphorus has entered or become intimately combined with the metal at plane 4.

7. More than one-third of the carbon has been taken up by the metal by the time it reaches plane 4; the remainder is taken up while the metal is in the bosh of the furnace and before it reaches the level of the tuyères.

8. The tolerant limit on sulphur is 0.05 per cent. At planes 4, 5, and 6 the metal contained approximately 140, 360, and 140 per cent, respectively, of the tolerant limit. At plane 4 the metal had taken up 3.33 per cent of the sulphur which had been charged into the furnace, while at plane 5 the metal had taken up 12.0 per cent of the available sulphur. The results show the ease with which the metal

has taken up sulphur in the upper part of the furnace; they also readily show that the metal continues to take up sulphur while it is in the bosh of the furance, probably due to the fact that part of the metal is not covered by slag, and therefore subject to contamination with sulphur produced from combustion of coke at the tuyère level.

9. Determination of forms of sulphur in coke samples at plane 4 shows that approximately 25 per cent of the sulphur has been removed from the coke by the time that it reaches this plane, and that the sulphur which has been removed is that which existed in the coke as ferrous sulphide and free sulphur. About half of the ferrous sulphide and free sulphur has been removed at plane 4.

10. Analyses of samples of limestone taken from plane 4 show that the lime has taken up 0.77 per cent sulphur, which is approximately 26 per cent of the available sulphur originally charged. Coke at this point has lost 25 per cent of its sulphur and the metal has taken up 3.33 per cent of the available sulphur. Preferential absorption of sulphur by lime in the upper part of the furnace is demonstrated by these results.

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